571

VOLUME 80 SEPARATE No. 571

PROCEEDINGS

AMERICAN SOCIETY
OF
CIVIL ENGINEERS

DECEMBER, 1954

EFFECTIVENESS OF SAND DRAINS ON NEW JERSEY TURNPIKE

by Charles M. Noble and
O. J. Porter, Members ASCE

SOIL MECHANICS AND FOUNDATIONS DIVISION

(Discussion open until April 1, 1955)

Copyright 1954 by the AMERICAN SOCIETY OF CIVIL ENGINEERS
Printed in the United States of America

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE $0.50 PER COPY

THIS PAPER

--represents an effort by the Society to deliver technical data direct from the author to the reader with the greatest possible speed. To this end, it has had none of the usual editing required in more formal publication procedures.

Readers are invited to submit discussion applying to current papers. For this paper the final date on which a discussion should reach the Manager of Technical Publications appears on the front cover.

Those who are planning papers or discussions for "Proceedings" will expedite Division and Committee action measurably by first studying "Publication Procedure for Technical Papers" (Proceedings – Separate No. 290). For free copies of this Separate—describing style, content, and format—address the Manager, Technical Publications, ASCE.

Reprints from this publication may be made on condition that the full title of paper, name of author, page reference (or paper number), and date of publication by the Society are given.

The Society is not responsible for any statement made or opinion expressed in its publications.

This paper was published at 1745 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N. Y.

EFFECTIVENESS OF SAND DRAINS ON NEW JERSEY TURNPIKE

Charles M. Noble,[1] M. ASCE, and O. J. Porter,[2] M. ASCE

SYNOPSIS

The paper describes the extensive use of sand drains under an unusually fast construction schedule on the New Jersey Turnpike in 1950 and 1951. Foundations for many heavy embankments ranging up to more than 50 feet in height over marsh muds extending to 100 feet and more in depth were stabilized. Data is included to show that the original estimates for filling and stabilization were properly conservative and that the treatment proved to be successful in spite of the rush nature of the work, in preventing lateral displacements, mud waves and shear failures during construction. Practically all of the consolidation and the settlement resulting therefrom was obtained during a construction period of one to two years by the use of properly spaced sand drains and appropriate amounts of overload which (1) permitted rapid loading of the marsh areas without causing failures, (2) hastened the primary consolidation, and (3) eliminated most if not all of the effects of secondary consolidation. Settlement data, the extent of patching required during the first three years of service under extremely heavy traffic and typical soil test results at three locations are included.

INTRODUCTION

The vertical sand drain method of stabilization as first described[3] in the proceedings of the International Conference on Soil Mechanics and Foundation Engineering (1936) has now been used for two decades. During the first ten years their use was limited to ten projects on the California Highway system,[4] one quay wall[5] and one dock and ammunition depot for the Navy in the San Francisco Bay area.

---

1. Chf. Engr., New Jersey Turnpike Authority, New Brunswick, N. J.
2. Cons. Engr., Porter, Urquhart and Beavin, Newark, N. J.
3. "Studies of Fill Construction over Mud Flats including a Description of Experimental Construction using Vertical Sand Drains to Hasten Stabilization."—by O. J. Porter, Proceedings, International Conference Soil Mechanics, Cambridge, Mass., 1936 Vol. I.
4. "Vertical Sand Drains to Speed Settlement of Muck-Filled Airport Sites."—by O. J. Porter. American Road Builders' Association, Bulletin #123, 1947.
5. "Failure of Quay Wall at Mare Island, California."—by L. C. Coxe, Capt. CEC, USN. Transactions ASCE, 1949 Page 499.

This paper will be limited to a discussion of the use of this method of treatment on the New Jersey Turnpike where a total of approximately five million feet of vertical sand drains were utilized to stabilize approximately twenty million cubic yards of muck beneath approximately twenty miles of four and six lane divided expressways. As indicated, the amount of stabilization required on this project probably exceeded all of the work of a similar character designed and constructed during the preceding fifteen years.

The project was also unique because it became necessary to complete the construction and stabilization at many locations in twelve to eighteen months to permit the construction of abutments and piers for the connecting bridges and to insure the on-time completion of the entire Turnpike. This rush program was essential because of the imperative need for the roadway facilities and to prevent the loss of in excess of $50,000 of interest charges and revenue per day.

The vertical sand drains were installed in various areas to depths ranging between 10 and 100 feet by the plugged mandrel method as previously described[6] in Civil Engineering, January 1952. Air pressure was used to expel the sand and to aid in pulling the mandrel. Steam pressure in lieu of air was also tried by a contractor on one or two projects on the Turnpike but this proved to be unreliable because the pressure was lost within the mandrel when the steam condensed on coming in contact with the cold sand particles.

Prior to constructing the embankments under a controlled rate of loading generally ranging from 1 to 4 feet of fill height per week, 1660 settlement platforms were installed on the original marsh surface to determine the rate and amount of settlement and for determining the pay quantities of borrow, measured in place, to which the contractor was entitled. Readings were taken all during construction on these platforms until the pavement was placed. Pore pressure measurements were also made at various depths in the mud to aid in determining progressively the degree of stabilization and the rate of loading permissible without causing displacement failures.

Because the construction procedure has been previously described, the remainder of this paper will be limited to a comparison between the preliminary estimate and the final quantities, the estimated and actual settlements and a discussion of the boring data and soil characteristics for three typical locations on the project.

Estimates and Costs Compared

Engineers and representatives of the bond-holders, are especially interested in the reliability of construction estimates. This is particularly true when a large portion of a project crosses deep and extensive marsh land where experience has shown that preliminary estimates were deficient because of the excessive displacement and settlement which occurred during construction. In numerous cases the yardage and cost of construction have been twice and even three times that originally estimated. In other cases the displacement has damaged adjacent facilities or required extensive and expensive corrective measures to be taken. As an example, on an eastern highway project in a swamp area, lateral movement and displacement in the form of mud waves extended 700 feet or more out from the embankment. In order to complete this project, it was found necessary to excavate the mud heaves

6. "Sand Drains Expedited Stabilization of Marsh Section, New Jersey Turnpike."—by O. J. Porter and L. C. Urquhart. Civil Engineering, January 1952, page 51.

to protect a nearby railroad, to remove the higher portion of the embankment approach and to extend the bridge structure to connect with the shortened and lowered fill.

Because of past experience in the Hackensack meadows (swamps), bridge designs, such as at the Belleville Turnpike overpasses over railroads, have provided for long structures connecting with very low embankments at each end.

Because of these previous experiences, the question was raised during the preliminary and design stages of the Turnpike by a number of contractors and engineers, as well as representatives of potential bond buyers, as to the feasibility of constructing heavy fills across the marshes in accordance with the stringent time schedule required for the construction of the project. Some contractors and engineers who had not had extensive experience with the sand drain method of treatment contended that the cost of such filling and stabilization work might prove to be double that estimated due to the large quantities of borrow material which they considered might be required to complete the roadway over the soft and deep meadow land. Because of the experience which the authors had had over a period of time ranging up to fifteen years on major projects involving similar problems in other parts of New Jersey and on the west coast, they were confident that embankments ranging up to 50 feet in height could be satisfactorily completed on schedule and within the estimates. This decision, which was approved and adopted by the Turnpike Commission, resulted in savings of many millions of dollars over the cost of constructing pile supported structures to connect with shallower fills.

Interest has been expressed in the estimates of quantities and costs and the performance of the project after the roadways have been in service a sufficient period of time to indicate the serviceability of the facilities and the probable maintenance cost thereof. Such comparisons are particularly significant on the northern 20 miles of the Turnpike where most of the roadway, with the exception of structures, is supported on marsh ground ranging up to 100 feet and more in depth.

The soil mechanics specialist is concerned with the detailed data on the soil test characteristics, estimated settlement, rate of settlement, and the actual performance of each representative embankment both during and subsequent to construction. This is important because any overall estimates on a project must be determined by experience and judgment based on voluminous detailed records for a project of this type. However, the overall values are more conclusive in proving whether the technical methods, interpretations and judgment result in sound and accurate final conclusions. The following comparisons of estimates and the actual cost for contracts which were constructed by the Turnpike Authority over the northern 18 miles of this express-highway (Sections 6 and 7—See Figure 1) are outlined below.

Preliminary Studies

A preliminary investigation to determine the location, design requirements and construction cost of the Turnpike was made in the summer of 1949 as a major portion of a feasibility study. This study included the making of 152 engineering test holes totaling 7, 155 lineal feet. These holes extended to a firm bottom and in numerous cases to depths ranging up to 150 feet. Many of the locations were inaccessible to drilling equipment and the test holes had to be limited to 1" hand-operated sampler holes made with Porter piston

type samplers operating from boats, weasles and light tractors equipped with marsh type hardwood track extensions. Substantial undisturbed core samples approximately 1" in diameter by 2 feet in length were obtained at 3 to 5 feet intervals. These samples were taken out of the ground and immediately tested for unit wet weight. A portion of these samples which were each 6" in length and contained in a thin brass tube, were retained and subsequently tested in the laboratory for moisture content and grain size. Test values of the mud varied greatly throughout the depths and in adjacent test holes. The large number of samples taken and tested for either unit weight or moisture content made it possible to arrive at average values for the depth and volume of mud which had to be considered in determining the rate and amount of settlement. The small cores of soil were also examined in the laboratory, both when wet and also as they were allowed to dry slowly in order to determine the presence and extent of silt or sand lenses. These would greatly affect the horizontal permeability of the muck formations, the spacing of sand drains required, the permissible rate of loading without causing major shear failures and the overall efficiency of the stabilization treatment. Two-inch undisturbed samples were next taken from representative locations for consolidation and triaxial shear tests. The total number of laboratory tests were as follows:

Water Content	1290
Grain Size	650
Plastic and Liquid Limit	45
Specific Gravity	85
Consolidation	116
Unconfined Compression	185
Triaxial Shear	17

The results of these foundation and design studies, which extended over the months of June, July and August of 1949, were published in a report made to the Authority by the Joint Venture of Ammann and Whitney, Edwards and Kelcey, Frederic R. Harris, Inc. and O. J. Porter and Company, under date of September 14, 1949. The settlement, fill quantities and costs referred to below as the preliminary estimate were made by the latter firm and were taken from this report.

Design Studies

After the feasibility of the Turnpike project had been determined, based on traffic and revenue estimates and the preliminary report referred to above, additional foundation investigations were made on a more detailed basis as part of the design studies. Seven hundred additional engineering test holes were made on the northern 18 miles of the Turnpike, aggregating approximately 24,000 lineal feet, to determine more accurately the extent, depth and the nature of the muck and the treatment required to insure on-time completion of the embankments, roadway pavements and the adjacent bridge piers and abutments. The test holes were generally made at 200 foot intervals or less, where the nature of the ground as disclosed by visual inspection and borings indicated significant variation. These borings and the corresponding laboratory tests, all designed to determine the stabilization treatment required, were of the same type as those described above for the preliminary report and estimates.

The preliminary and design estimates included a contingency factor of 15 per cent over and above the amounts shown below to allow for increased settlement or some possible minor displacement before the sand drains were installed. This is too small a contingency item for marshland construction based on experience with uncontrolled filling without sand drains, but it was considered ample to safeguard the financial status for completion of the Turnpike. It is gratifying to report that there was no over-run in borrow quantities in these sections.

Estimates Compared

The estimates as published in the preliminary report of September 14, 1949 included approximately $22,900,000 for borrow, sand blanket and special subgrade materials for constructing the roadway embankments and service areas on the northern 18 miles of the Turnpike. The design estimate on which the contracts were based amounted to $23,976,000. The actual cost, including claim settlements approved, totaled approximately $19,500,000. This is $3,400,000, or 15 per cent, below the preliminary estimate.

The average estimated price for all of the borrow measured in place, including the sand blanket and selected subgrade material, was $1.84 per cubic yard. The actual average cost was $1.61 per cubic yard. This average unit price was 12-1/2 per cent below the preliminary estimate which accounts for about $2,860, 000 of the $3,400,000 saving.

The fill yardage as estimated in the preliminary report was 12,430,000 cubic yards. This was based on in-place measurements in the embankments including all of the allowances for settlements which approximated 2,100,000 cubic yards. The final yardage actually used was 12,062,000 cubic yards, or approximately 3 percent less than the quantities included in the preliminary estimate.

Sand Drains Estimates

The preliminary estimate on the northern 18 miles of the Turnpike (Sections 6 and 7) provided for 3,288,000 lineal feet of sand drains at an average price of $.90 per lineal foot, or $2,960,000. The actual quantities used were 4,002,000 at an average bid price of $.56 per lineal foot, totaling approximately $2,245,000. This resulted in a saving of slightly more than $700,000 in this item over the allowance made in the preliminary report. The increase in footage was necessary due to changes in plan and particularly by the much faster time schedule required due to delays in starting construction. Because of difficulties, actual construction was not started in many areas until 6 to 9 months after the time assumed when the preliminary estimates were made.

The bids received on the sand drain work were very gratifying. They ranged from $.40 to $.45 per lineal foot for 15 inch diameter drains of 70 feet to 100 feet in depth, to $.70 to $1.00 per lineal foot for 20 inch drains ranging from 10 feet to 35 feet in depth. The longer drains were less expensive because of the relative reductions in the equipment moving costs. The favorable bid prices received for this large volume of sand drain work were substantially lower than had been obtained on similar work prior to that time. These favorable results were undoubtedly influenced by the following developments which occurred prior to the start of the Turnpike work:

1. Before the Turnpike Authority was established by an act of the legislature, the Highway Department held several meetings with the New Jersey State Contractors Association for the purpose of informing the contractors regarding the feasibility of using sand drains and the best methods of quickly installing them to depths of 100 feet.

2. Sand drain work was next included in a major contract for stabilizing ground from 90 to 100 feet in depth at the location of the Paterson Plank Road Overpass across Route 3 near Secaucus, New Jersey. George M. Brewster and Sons submitted the lowest proposal for the entire project, which included a bid of $1.15 per lineal foot for installing 105,000 lineal feet of drains to depths of 80 to 100 feet. This project created a great deal of interest among engineers and contractors in the area. Time studies were made by many engineers and contractors which indicated that long sand drains could be installed by the plugged mandrel method in six to eight minutes each. The Brewster firm used its ingenuity and completed the work very satisfactorily and in record time even after some delays were encountered in developing the proper techniques and methods for quickly filling and then extracting the mandrel from the ground. The stabilization treatment on this project was entirely satisfactory and inasmuch as it was located in a representative marsh area of the Hackensack meadows, the results served as a large scale pilot test for the much more extensive work on the Turnpike.

3. In connection with the work discussed under 2, the McKiernan-Terry Corporation improved the sand drain equipment previously designed by the Junior Author. They reduced the equipment maintenance costs by developing a more substantial design for the top of the mandrel, using special, high-grade, heat treated steel. They also designed, using appropriate high strength steel, where necessary, a lighter sectional set of compression leads of 120 feet in length, which could be more readily handled with mobile cranes to rapidly install the drains to 100 feet in depth. These compression leads were designed so that they could be used also for 40, 60 and 80 foot lengths of drains. A lighter traveling sand skip with an improved gate was developed as a part of the outfit. Experience in connection with the installation of 4,000,000 feet of drains on this 18 mile section of the Turnpike showed that hammer failures were one of the largest causes of expensive shut-downs and delays in installing the drains. This was an unexpected development as most of the drains drive very easily. Long run-downs are common in the soft material where the weight of the hammer and mandrel alone are sufficient to penetrate to great depths. Further improvements in hammers especially designed for sand drain work are desirable. Standard hammers hitting a hard blow absorb internally much of the shock when the mandrel instantly falls away after a blow is struck.

Sand Drains Spacing

The sand drain spacing ranged from 6 feet to 14 feet. In general, closer spacing was used under the higher fills in the vicinity of bridge abutments to allow a more rapid rate of loading and earlier removal of the overload, thus permitting construction of the abutment and the adjacent piers while other portions of the embankments were being filled and stabilized.

At other locations drains were spaced 7 to 10 feet apart immediately below the proposed roadway and 8 to 12 feet apart below the embankment slopes and berms where the load was less and the need for a high degree of stabilization was not essential. In a few cases the spacing of the drains ranged from

11 to 14 feet under the main portion of the embankment where the height of filling required was small and the mud consisted of partially decomposed fibrous vegetable growth of less impervious nature.

Sand Drain Design

The first objective of the sand drain design was to provide sufficient increase in strength in the underlying mud to allow for the fill to be placed at a controlled rate of loading without causing displacement and mud waves. Initially, most of the mud had a shear strength ranging between 150 and 400 pounds per square foot. Certain it is, that large displacements would have occurred under fills of more than 8 to 10 feet in height on this section of the Turnpike if sand drains had not been installed. This would have required large increases in the quantities of high priced borrow which, based on past experience with the displaced method, might range up to two to three times the volume of mud inside of vertical slopes below the proposed embankments. The cost of the extra fill which would have been required, using the displacement method, undoubtedly would have greatly exceeded the cost of the sand drain treatment on this project where, due to the long hauls required, the price of borrow was high.

The fact that the mud was sufficiently soft, initially, to displace under the weight of a 6 to 8 foot fill over most of this project, is shown by the fact that visual mud waves started to form in numerous cases where the contractor placed approximately 4 feet of sand blanket topped with 2 to 3 feet of other granular material to form a working table. This occurred before installing the sand drains and without waiting for the upper portion of the mud to consolidate partially under the weight of this initial load. The problem was solved generally by the contractor on his own initiative because he did not want to use any more than the minimum amount of the high cost sand blanket and granular material. Under the specifications the contractor was paid only at one average bid price for all borrow based on the in-place measurement within the design slopes. Any over-run in the high cost material required near and below the water line increased his overall expense.

In most cases, the contractors avoided displacements by spreading the sand blanket ahead over the marsh in a thin layer and using flat slopes. The trucks were end dumped 50 feet or more back from the outer edge of the fill. Light bulldozers or bulldozers equipped with long blade extensions were used so that the weight of the bulldozer would not displace the mud near the outer edges of the spread. In a few particularly difficult locations on some contracts, the first 2 to 3 feet of sand was cast ahead with a small clam shell bucket in order to avoid the formation of mud waves and boils. This then made it possible to spread an additional 2 or 3 foot layer of sand with bulldozer equipment and to avoid the expense of removing any mud waves or boils from beneath the embankment area. Bulldozers with marsh type hardwood track extensions would also help to avoid displacement and thus help to reduce the amount of sand required to obtain a continuous free-draining layer entirely across the bottom of the embankment.

On this portion of the Turnpike, the sand drain method generally accomplished the first objective of eliminating all major displacements. The rate of filling was carefully controlled so that the mud would gain sufficient strength to support subsequent layers of fill. It was necessary in a number of cases, however, to slow down or delay the filling for a week or two, as provided for in the specifications, when signs of instability developed. This

was detected by excessive pore pressure and by small horizontal and vertical movements on the fill control stakes which were placed and closely observed in rows along and adjacent to the outer limits of the fill. Due to the rush nature of the project, the rate of filling permitted did not provide for as much of a safety factor as desired. As a result, minor slippages, but apparently insufficient in amount to damage the drains, occurred at two locations.

The first case was at the south embankment approach of the Passaic River Bridge. In this case, a crack occurred in the main embankment and a slight bulging was observed in the ground adjacent to the fill along Raymond Boulevard. The contractor had placed approximately a 5-foot layer of fill the previous night by the hydraulic method. This added about double the load increment permitted under the specifications. The water from the hydraulic operations also saturated and increased the weight of the entire sand fill. The immediate result of this was that the pore pressure increased about 12 pounds to a total of 15 pounds from this one increment of filling. No further difficulties developed, however, in completing this fill after allowing a short rest period and requiring the contractor to place the remainder of the embankment and overload by the dry fill method.

In the second case, a 45 foot high section of the embankment, approximately 150 feet in length, between the Delaware, Lackawanna and Western Railroad Bridge and the Erie Railroad Bridge slipped out horizontally about 5 feet into the ditch between the Turnpike and Pennsylvania Railroad. This movement occurred over a reinforced concrete pipe culvert which passed under the Turnpike at this location. The movement caused failure of the culvert and it had to be plugged with sand to avoid complete collapse and further settlement. The drainage ditch was then relocated to flow through a new culvert placed at the toe of the embankment adjacent to the Delaware, Lackawanna and Western Railroad. After a rest period of three weeks, this embankment was built up about 5 feet to overload grade. No further trouble developed either during or subsequent to construction. The cause of this minor movement during the construction stage has not been definitely determined, but investigation indicates that the sand drains had not penetrated through all the compressible materials and that an adequate thickness of pervious blanket had not been uniformly placed throughout the area. Observation and borings showed that there was no sand blanket material immediately adjacent to the culvert throughout its entire length. It appears that this had either been omitted in the culvert area due to the fact that the plans required trench excavation and pervious backfill as part of the culvert construction, or that the sand blanket construction as planned had been destroyed during the culvert installation.

While the developments at both of these locations, as considered retrospectively, are minor incidents in the construction of this project, they were of major importance at the time because any serious failure of even one short stretch on the 118 mile Turnpike might have delayed its opening and the collection of large sums per month in tolls which are so vital on a major revenue bond project.

The second objective of the sand drain design was to obtain most of the consolidation and settlement during the construction stage. This, or course, involved some degree of calculated risk. Modifications of this second design objective were also necessary where the mud and compressible materials exceeded 100 feet in depth and in other locations where it was considered economical to raise the grade to allow for future settlement and to patch limited areas subsequent to construction. Included in this broad classification are three miles of road supported on shallow embankments of 10 to 15

feet in height between Route 3 and Route 6. In this area some engineers advocated filling without any sand drain treatment. Because of the displacement hazards, this latter scheme was not used, but the sand drains were installed only 20 to 30 feet in depth through the upper soft layers of muck, rather than to depths of 70 to 100 feet which could have been accomplished at a cost ranging between $200,000 and $250,000. The grade of this "floating" portion of the road was raised 1 to 3 feet to allow for additional settlement over a period of years. Some portions of this section have now settled 4 to 12 inches. The differential settlement, however, has not been sufficient during the past two and one-half years to require patching until recently. This work was limited to two areas totalling approximately one-half mile in length.

The degree to which this second objective was accomplished by the sand drain method at other locations is indicated by the factual settlement records hereinafter summarized and the patching records for 1952—1954, which are briefly discussed in the following paragraphs.

Patching and Resurfacing Required 1951—1954

With the exception of the "floating" fill north of Route 3, the only locations which have or will require patching during the first three years of operation of this section of the Turnpike are limited to the following nine areas:

	Location of Resurfacing	Date	Length in Feet	Sq. Yds.	Average Thickness in Inches
1a.	N. Approach to Morses Creek Bridge	1952	5	36	1 - 2
1b.	S. Approach to Morses Creek Bridge	1952	25	233	2 - 3
2.	N. Approach to Railroad Ave. Viaduct (Standard Oil Refinery area)	1953	100	816	2.6
3.	S. of Old Bayway Ave., Elizabeth	1953	575	5367	2.6
4.	S. Approach Elizabeth River Bridge (1/2 width, Central 4 lanes only)	1954	225	1200	2.9
5.	N. Approach Elizabeth River Bridge	1953	311	2421	6.7
6.	N. Approach Bound Creek Bridge, Newark Airport	1954	750	4000	3.5
7.	Culvert S. of Port St., Newark Airport	1954	432	3700	2
8.	S. Approach Passaic River Bridge	1954	187	1822	3
9.	Opposite Serv. Area #12, Secaucus (Estimate - Old pig pen area)	1954	2400	19200	3
	Total		5,010	38,795	
	Total Asphalt Pavement Northern 18 miles			735,000	

In the first area, minor patches were required within less than a year after opening the Turnpike at both approaches to Morses Creek Bridge in Linden. The original contract plans required the removal of all of the mud back of the abutment for approximately 50 feet. Minor settlement here was undoubtedly due to compaction of the backfill and consolidation of any mud not completely removed.

In the second area, the embankment was placed over an old railroad yard which had been in place for many years. Placement of the embankment and overload was delayed due to the necessity of relocating a railroad storage yard. In addition to this, the major portion of the settlement also occurred immediately adjacent to the abutment where past experience on many projects has indicated that the placement of backfill behind the abutment may have contributed in a major way to the settlement and as a result the patching required. This is supported by the fact that many highway backfills have required patching in this area even though the embankment was placed on firm ground.

The third area where patching has been required was over relatively firm ground to the south of Bayway Avenue in Elizabeth where no sand drains were installed. This patch merely took out pavement roughness which developed during the first two years.

In the fourth and fifth areas, the mud was excavated back of the abutments at the approaches to the Elizabeth River Bridge. In this area, the settlement approached a maximum of 11 inches within 65 feet of the abutments. The patching requirements undoubtedly were influenced by compaction of the backfill behind the abutments and the consolidation of soft material which may not have been completely removed under water by the excavation and backfill method.

In the sixth area, a relatively thin patch was required to smooth up the north approach to the Bound Creek Bridge. Part of this settlement probably did occur due to consolidation of the backfill material but it is also known that all of the overload had not been placed during construction and then allowed to remain for the entire period contemplated by the design.

In the seventh area, an average settlement of 2 inches occurred adjacent to a pile-supported drainage culvert constructed for the airport many years ago. The roadway over this area of the marsh land produced a rough ride because of the one firmly supported strip which extended completely across the Turnpike. In this area, the half-moon type of extra overload provided in the design was not placed due to the rush in the construction program. If the total overload, as contemplated by the design, had been placed and allowed to remain for the period contemplated, it is probable that the amount of differential settlement may not have been significant.

At the eighth location, patching has been required during 1954 to smooth up the approach to the south end of the Passaic River Bridge. Part of this settlement was due to consolidation of the backfill behind the abutment as settlement of only three-eighths of an inch was found 200 feet out from the abutment. A portion of this settlement, however, was anticipated adjacent to the abutment as it was necessary to remove the overload after a stabilization period of about one month or one-third the minimum time contemplated in the original design assumptions. If the job were done over again, 5 to 8 feet of additional overload would be used and it would be hoped that the time would not be shortened for filling and stabilization. An embankment and settlement record for this area is shown in Figure 2.

The ninth area where patching will be required this year is the old pig farm area of Secaucus. While the pavement in this area has given good

service during the last two and one-half years, waves have developed over a distance of about 2,400 feet to the point that resurfacing is required. Much of the pig refuse, ranging up to 15 feet in depth, was removed to the original marsh level during construction of most of this area. Sand drains were installed on 14 foot centers to a depth of about 15 feet through this area after as much as possible of the pig muck had been removed to marsh level. The short lengths of the "waves" of differential settlement is the major cause of the patching required.

While the exact cause of the differential settlement in this area cannot be definitely determined, the following factors have undoubtedly contributed to a major extent:

1. The muck was removed with dragline and clamshell buckets as the fill was placed because no other method could be used to support the equipment. The muck squeezed out from beneath the fill, forming mud waves which were then removed by the equipment prior to advancing the fill. This method inherently produces a non-uniform depth and penetration of the fill into the soft material. Undoubtedly some of the mud became mixed with the sand blanket and granular material so that a uniform and continuous pervious layer was not obtained under the entire embankment to insure good drainage.

2. A portion of the initial operation in this area was carried on at night and while inspectors were assigned to the work at all times, there is a possibility that a satisfactory grade of sand blanket was not placed uniformly under the entire area. In addition to this, the drainage layer at the top of the sand drains may have become partially plugged in some areas with liquid muck.

3. The drains were placed on 14 foot centers under this relatively light embankment. This spacing of drains is not now considered adequate for the 4 foot overload used and for the shortened time this overload remained in place as dictated by the high speed schedule of the Turnpike.

Partial Summary of Treatment and Settlement Records

Readings on the pipes extending up from the settlement platforms were taken at least weekly while the embankment was being constructed and then at least monthly during the settlement and stabilization period and until the pavement was placed. Level readings have also been taken since construction on top of the pavement in many of the areas in order to determine the degree of stabilization obtained.

Table I is a partial list of the settlement platforms at other typical locations where no patching has been required. It also includes the significant data on the height of the embankment, the height of the overload, the depth of the mud, spacing of the sand drains directly below the roadway level at each location, and the total amount of settlement which occurred during construction. Settlement readings in these areas were obtained during September and October of 1953. The average settlement for the two lanes of pavement since initial construction is also shown in Table I. Most of these locations were in the vicinity of embankment approaches to structures and they have been purposely selected because this is where any settlement of either the backfill or the embankment foundation would most readily affect the riding qualities of the Turnpike. Table I also includes the average settlement figures for the two roadways at 50, 100 and 200 feet from the abutments. A study of these data will indicate whether the minor settlements which have occurred were

induced by consolidation of the backfill. It should also be pointed out that the spacing of the drains as shown in Table I may, in many cases, be one or two feet less than the actual spacing used at 100 and 200 feet out from the abutments. In studying this table, it also should be assumed that, except for the patched areas discussed above, these settlement observations in general represent the extremes on this eighteen mile portion (Sections 6 and 7) of the Turnpike. They were selected on this basis because no level readings were taken in 1953 over large areas of the pavement which showed no signs of settlement or roughening.

The data reported above and careful inspections which have been made periodically again this year (1954) clearly show that the sand drain treatment was effective in obtaining practically all of the settlement during construction. Small uniform settlements of 1 to 3 inches are considered normal as such amounts of settlement often occur due to the pounding of traffic and consolidation of fills even when they are extremely well constructed on firm ground. Differential settlement is the principal cause of unsatisfactory riding qualities.

Soil Tests and Settlement Data

It would be cumbersome to summarize all of the soil test data on the approximately 18,000 samples of mud which were taken and tested from approximately 30,000 feet of borings made in connection with the design of this project. These determinations included about 350 consolidation tests and approximately 175 shear strength tests by triaxial methods at various stages of consolidation. Test data at three locations are hereinafter presented as examples of the extensive data which was obtained and analyzed in order to intelligently design and control the work. These three examples are:

1. South approach to the Hackensack River Bridge
2. North approach to Turnpike bridge over Route 3, Secaucus, New Jersey
3. South approach to the Turnpike structure over the New York, Susquehanna and Western Railroad near the northern end of the Turnpike.

Borings Logs and Soil Tests

The mud at all three of these locations exceeded 70 feet in depth and therefore a comparison of the estimated and the actual amount of settlement is particularly significant. Typical borings for all three of these locations are shown on Fig. 3. Test results for peat as shown on Fig. 4 can be considered as representative of the upper highly organic layer which is found to depths generally ranging from 3 to 12 feet in the deep portions of the Hackensack Meadows.

South Approach to Hackensack River Bridge

Typical soil tests at this location are shown on Figs. 4, 5 and 6 and in Table II. It will be noted from Fig. 3 and Table II that soft clay (mud) containing 40 to 80% of clay particles and 40 to 50% of moisture extended to depths of approximately 80 feet.

Fig. 7 shows layout of the closely spaced drains in the abutment area where the embankment was widened to avoid increasing the load in this critical location when future roadways are required. With this exception, the drains were spaced 8 to 12 feet apart under the major portion of this embankment approach.

Figs. 8 and 9 show the rate of loading and the amount of settlement estimated during the preliminary and design stages. It will be noted that the actual settlement closely agrees with the estimated values and that the stabilization was completely effective. No patching of this embankment approach has been required to date and measurements show that the settlement since the pavement was placed is less than 1 inch as measured in 1953 for a distance of 200 feet south of the abutment.

North Approach to Turnpike Bridge over Route 3, Secaucus, N. J.

Typical soil test results are shown on Figs. 10 and 11 and in Table III. The soft mud ranged from 60 feet near the abutment to 100 feet approximately 200 feet to the north. The settlement during construction ranged from 8 to 10 feet in this area, which closely agrees with preliminary estimates.

Fig. 12 shows the embankment and settlement record, together with the estimated settlement at one location. It will be noted that the stabilization treatment was highly satisfactory. Level measurements taken in 1953 show that the pavement ranged from 1/4 inch below to 5/8 inch above theoretical grade for a distance of 200 feet out from the abutment. Obviously no patching has been required.

South Approach to Turnpike Bridge over New York, Susquehanna and Western Railroad

Typical soil tests are shown on Figs. 13 and 14 and on Table IV. It will be noted that soft material consisting primarily of clay containing 40 to 60% of water extended to depths of 110 feet. Because of the delays which occurred in starting construction, the number of sand drains was increased and the spacing reduced to 6 and 8 feet in the high fill approach area as shown on Fig. 15. It will be noted that settlement of approximately 13 feet, which closely agrees with the preliminary estimate, occurred during the construction and short stabilization period. The treatment was entirely effective even under this deep mud condition and the adverse requirements for speed. No patching of this approach has been required during the two and one-half years the roadway has been in service. Level readings show a settlement up to approximately 2 inches for a distance of 200 feet out from the abutment.

Discussion of Soil Tests and Stabilization

Conventional soil tests show that the soft foundation materials encountered were very impervious and that they are similar but not identical in this respect to the so-called organic silt and soft clay formations deposited during recent geological times in tidal areas on both the east and west coasts of North America. The deep unconsolidated clay (mud) in the Hackensack Meadows, however, is generally unlike the marine muds ("organic silts") found at LaGuardia Airport and Manasquan River, because it is varved, containing numerous very thin lenses of silty sediments which have a higher permeability than the soft clay formation in which they are deposited. It is difficult to obtain reliable information from small scale tests on the horizontal permeability of these varved formations, but laboratory tests and experience indicate that effective values of 1 to 3 times the vertical permeability may be used with vertical sand drains of 15 to 20 inches in diameter. Test results of limited value plus judgment based on past experience and examination of undisturbed cores must for the present be relied upon to

guide the engineer in predicting the probable horizontal permeability and the action of such materials under the vertical sand drain method of treatment.

Sand Drains in Other Sections

Vertical sand drains were installed by the New Jersey Highway Department and the Turnpike Authority at six other locations in Sections 1, 2 and 5 where alternate bid prices showed savings over the cost of excavating and replacing the soft materials. The treatment at four of these locations has proven satisfactory and no patching has been required to date.

At one location, the sand blanket as placed was not sufficiently pervious. Gravel filled trenches were ultimately placed over each row of sand drains to allow the water to escape. The fill was finally completed to grade just in time to permit opening of the Turnpike but without placing any of the overload adjacent to the abutment as originally planned. At the second location, all of the work was complete according to plan, except that the upper portion of the fill and the overload was not placed until a few days before it was necessary to remove the overload to complete the pavement for opening of the Turnpike. Obviously, insufficient time was provided, in both cases, for proper consolidation. At these two locations, patching has been required, during 1952 and 1953, adjacent to the solidly supported structures, to bring the pavement up to grade. The mud at these two locations was only 15 to 40 feet in depth but otherwise similar to the soft material encountered in the other four areas, which leads to the conclusion that all of the details of sand drain design and construction procedures are essential to insure on-time completion and good results.

CONCLUSIONS

The results as shown by the estimates and performance on this major project indicate the following conclusions:

1. Vertical sand drains can be used with confidence on major projects to effect large savings in construction costs if intelligently conducted preliminary foundation studies are made to determine the proper design and cost of the work.

2. Heavy embankments up to 50 or more feet in height can be constructed economically on relatively impervious soft mud formations in less than two years if the sand drains are properly spaced and adequate overload is placed and then allowed to remain a sufficient length of time to overcome the possible effects of secondary consolidation.

3. All of the details of sand drain construction, including the permeability of the sand blanket, the need for gravel windrows or other horizontal drains to readily remove the water from the sand blanket as it filters up from the vertical drains, the permissible rate of loading, the amount of overload and especially the time factors involved, are of utmost importance to successful construction.

4. The performance of the sand drain treatment on the Turnpike was highly successful from an economical standpoint, and the preliminary estimates were not exceeded.

5. The high fill approaches to bridges were designed initially to allow for a minimum settlement period of 90 days under full overload. Difficulties and delays which developed due to various causes greatly shortened this stabilization period. However, in general, it was still feasible and economical to compensate for the adverse time schedule by decreasing the spacing of the drains and increasing the amount of the overload. Nevertheless, it would be desirable on future work to plan on a minimum stabilization period of six months wherever possible or for the use of heavy overloads and close spacing of drains when shorter periods are unavoidable.

TABLE I

PARTIAL SUMMARY OF SAND DRAIN TREATMENT AND SETTLEMENT RECORDS

Sections 6 and 7 - New Jersey Turnpike

(All figures in feet unless otherwise noted)

Station	Location	Total Ht. of Embank.	C. L. Used	Depth of Mud	Sand Drain Spacing	Total Sett. During Construction	Additional Settlement since Paving			
							This Location	Distance from Abutment 50	100	200
20+00	70'S. of Railroad Ave. Viaduct	39	10	21	8	3.0	0.02	0.03 †	0.08 †	0.16
269+00	800'S. of Bound Cr., Eliz., NJ	12	5	17	10	2.3	-	0.18	0.13	N*
353+00	197'S. of Oak Is. Bridge, Newark Interchange Area	44	6	15	7	3.1	-	0.16	0.15	N
431+00	555'S. of Bridge over CRR of NJ	50	8	14	10	2.0	-	0.06	0.12	N
537+00	102'N. of Passaic River Bridge	56	12	69	7	5.9	0.05	0.05	0.05	0.03
557+00	63'S. of Bridge over Belleville Turnpike Road	38	10	99	7	6.3	0.02	0.04	0.03	0.02
560+35	56'N. of Bridge over Belleville Turnpike Road	42	12	90	7	7.1	0.02	0.03	0.07	N
659+00	240'N. of Bridge over Delaware Lackawanna & Western RR	51	4	19	10	5.9	-	0.24	0.23	N
664+50	42'S. of Bridge over Erie RR	47	4	16	10	4.1	0.09	0.10	0.14	0.16
684+00	530'N. of Bridge over County Ave., Secaucus	35	4	15	14	5.0	-	-	-	-
768+00	67'S. of Bridge over Paterson Plank Road, Secaucus	39	10	30	8	4.2	0.07	0.07	0.05	0.10
771+00	82'N. of Bridge over Paterson Plank Road, Secaucus	52	12	37	8	7.9	0.04	0.07	0.05	N
776+00	95'S. of Bridge over Route 3, Secaucus	54	13	55	7	9.5	† 0.03	† 0.02	† 0.05	-
956+00	85'N. of Bridge over N.Y. Susquehanna RR	46.5	10	96	7	6.5	0.10	0.12	0.20	0.40
993+00	253'N. of Overpeck Cr. Bridge	15	6	67	10	3.0	-	0.02	0.03	0.03

*"N" indicates no settlement apparent to survey party and levels not taken.

TABLE II

TESTS BORING NO. 1 SOUTH APPROACH HACKENSACK RIVER BRIDGE

Elev.	Unit Weight lbs./Ft.^{3}	Water Content % Dry Wt.	Grain Size Analysis			Atterberg Limits		Spec. Grav.	Com. Str. Tons/Ft.^{2}
			Sand	Silt	Clay	L. L.	P. I.		
-14.5			0	50	50				.79
-19.0	122	30	3	75	22				.88
-34.0	112	39	5	27	68	31	8		.28
-39.5	112	42	0	19	81				.34
-44.0			3	12	85				
-44.5	108	49				32	12		.32
-49.0			0	17	83	36	14		.33
-49.5	109	51						2.65	.34
-54.5	109	47	0	14	80	33	14		.45
-59.0			0	22	78	37	17		.15
-59.5	108	48				37	10	2.65	.23
-64.5	113	42	26	34	40				
-69.0			0	22	78	33	17		.30
-69.5	112	40						2.65	
-74.5	111	44	0	25	75				.29
-79.5	126	23	43	48	9				

* Equals the difference between the major and minor stress as measured the unconfined and triaxial test.

TABLE III

TESTS	BORING NO. 2		NORTH APPROACH TO ROUTE #3 OVERPASS						
Elev.	Unit Weight	Water Content	Grain Size Analysis			Atterberg Limits		Spec. Grav.	Com*Str.
	lbs./Ft.^{3}	% Dry Wt.	Sand	Silt	Clay	L. L.	P. I.		Tons/Ft.^{2}
-12.5	114	38	3	39	58				
-14.5	116	35	0	40	60				
-17.5	114	38	0	20	80				0.29
-19.0	111	44	0	17	83				
-22.0	107 108	49 47							0.17
-22.5	103	62	0	15	85				0.13
-27.0	105 104	55 57							0.17
-27.5	105	62	0	10	90				0.10
-28.0	104	59	0	15	85	42	17	2.77	
-31.5	104	56							
-32.0	104	58							
-32.5	106	52							0.17
-33.0	106	52	0	13	87				0.18
-37.5	112	42	1	34	65				0.14
-38.0	117	33	3	51	46			2.68	
-56.5	117	31	3	84	13				
-57.0	128	25	17	44	39				0.08
-57.5	122	32	8	41	51	28	8	2.63	

*See TABLE II

TABLE IV

TESTS BORING NO. 3 S. APPROACH TO SUSQUEHANNA R.R. OVERPASS

Elev.	Unit Weight Lbs./Ft.^{3}	Water Content % Dry Wt.	Sand	Silt	Clay	Atterberg Limits L.L.	Atterberg Limits P.I.	Spec. Grav.	Com*Str. Tons/Ft.^{2}
-14.5	106	54	14	36	50				0.59
-15.0	115	37	13	40	47			2.12	
-25.0	115	41	27	16	57	40	17		0.31
-26.0	114	40	24	20	56			2.43	
-35.5	119	32	38	14	48				0.50
-36.5	119	34	38	14	48				0.50
-37.0	119	34	40	20	40			2.58	
-47.0	108	48	0	13	87				0.26
-47.5	105	50	5	12	83			2.51	
-60.0	106	50	0	15	85				0.15
-60.5	108	48	4	13	83			2.75	
-71.0	112	43	6	12	82				0.18
-71.5	105	57	4	13	83			2.40	
-80.5	100	68							
-81.0	110	43	8	10	82			2.61	
-90.5	109	48							0.16
-91.0	105	51	0	14	86	49	27	2.72	0.34
-109.5	111	45							
-110.0	106	49	0	18	82			2.57	

* See Table II

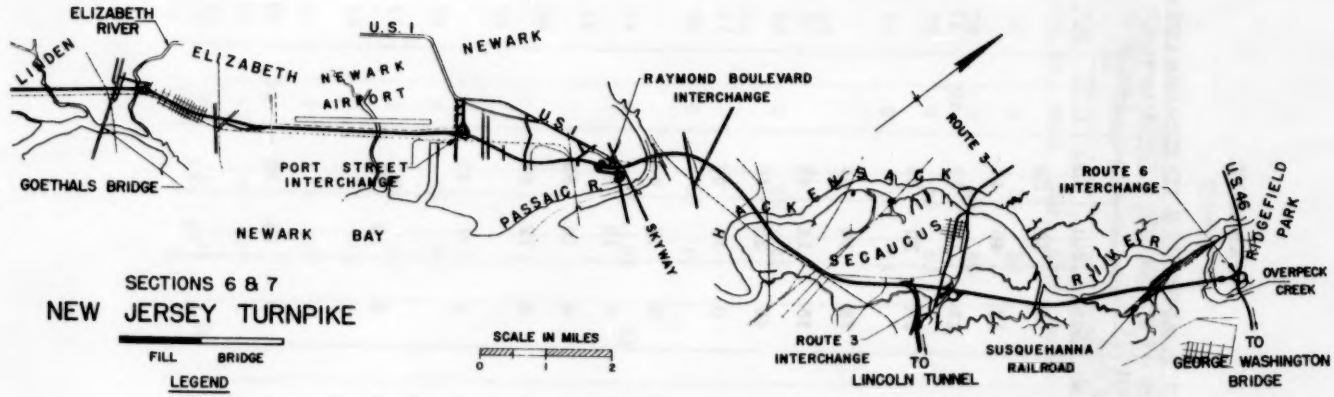
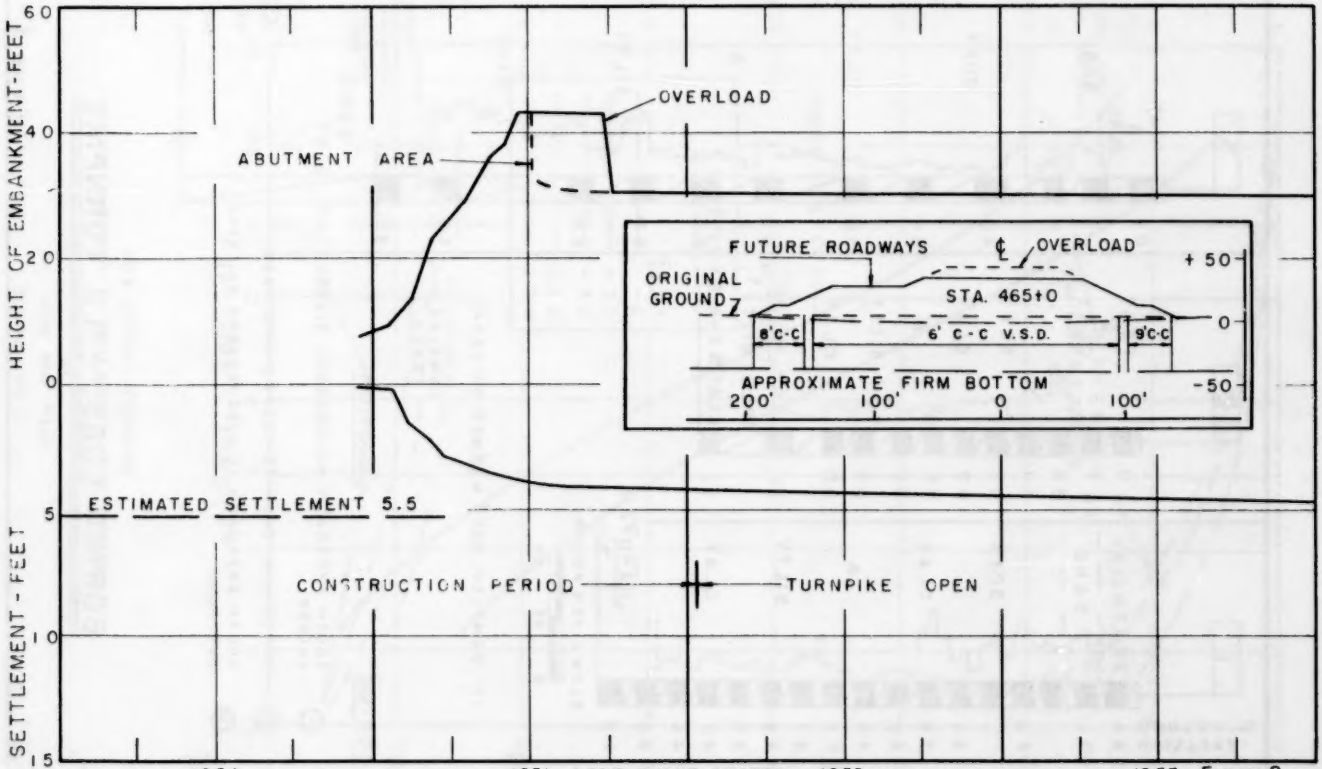

ELIZABETH RIVER
LINDEN
ELIZABETH
NEWARK AIRPORT
U.S. 1
NEWARK
RAYMOND BOULEVARD INTERCHANGE
GOETHALS BRIDGE
PORT STREET INTERCHANGE
U.S. 1
PASSAIC R.
SKYWAY
NEWARK BAY
HACKENSACK
SECAUCUS
ROUTE 3
ROUTE 6 INTERCHANGE
U.S. 46
RIDGEFIELD PARK
OVERPECK CREEK
ROUTE 3 INTERCHANGE
TO LINCOLN TUNNEL
SUSQUEHANNA RAILROAD
TO GEORGE WASHINGTON BRIDGE
SECTIONS 6 & 7
NEW JERSEY TURNPIKE
FILL
BRIDGE
LEGEND
SCALE IN MILES
0
1
2

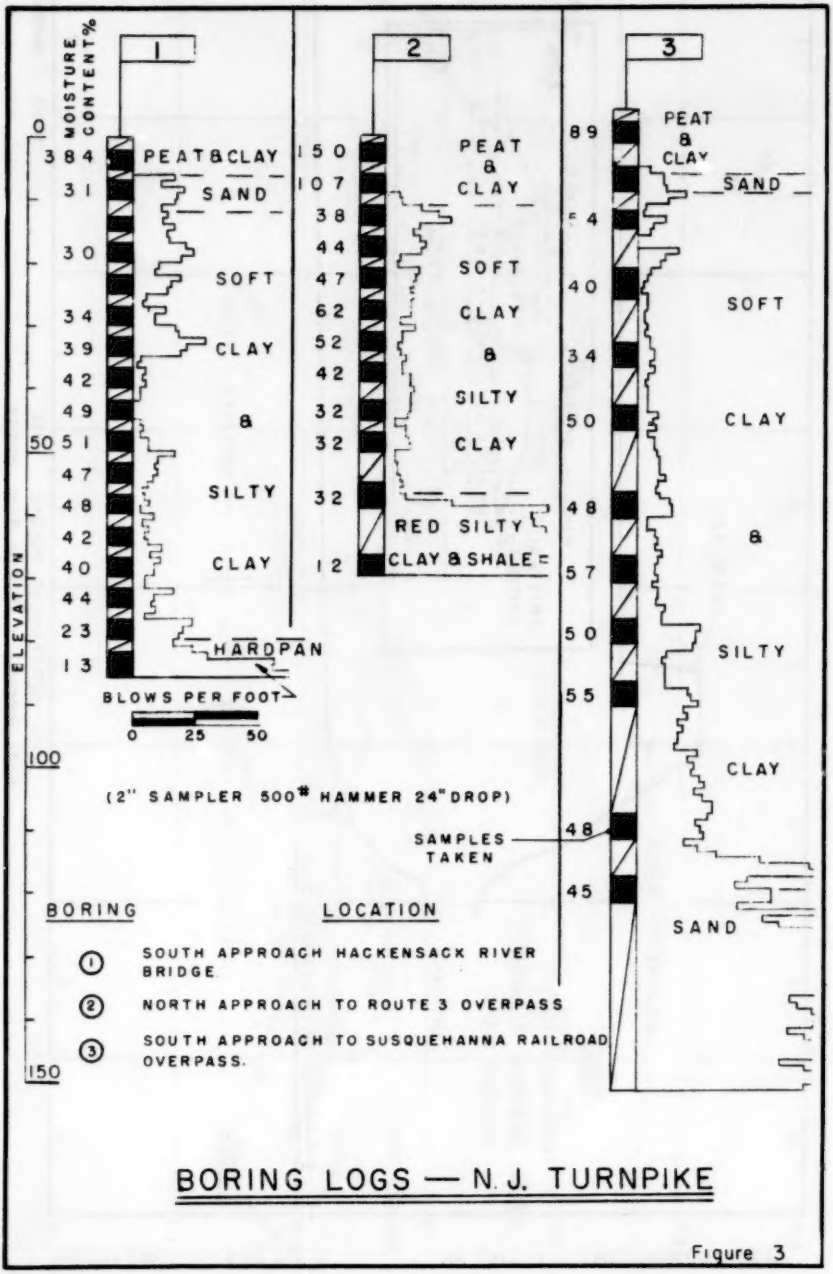
Figure 1



SETTLEMENT RECORD

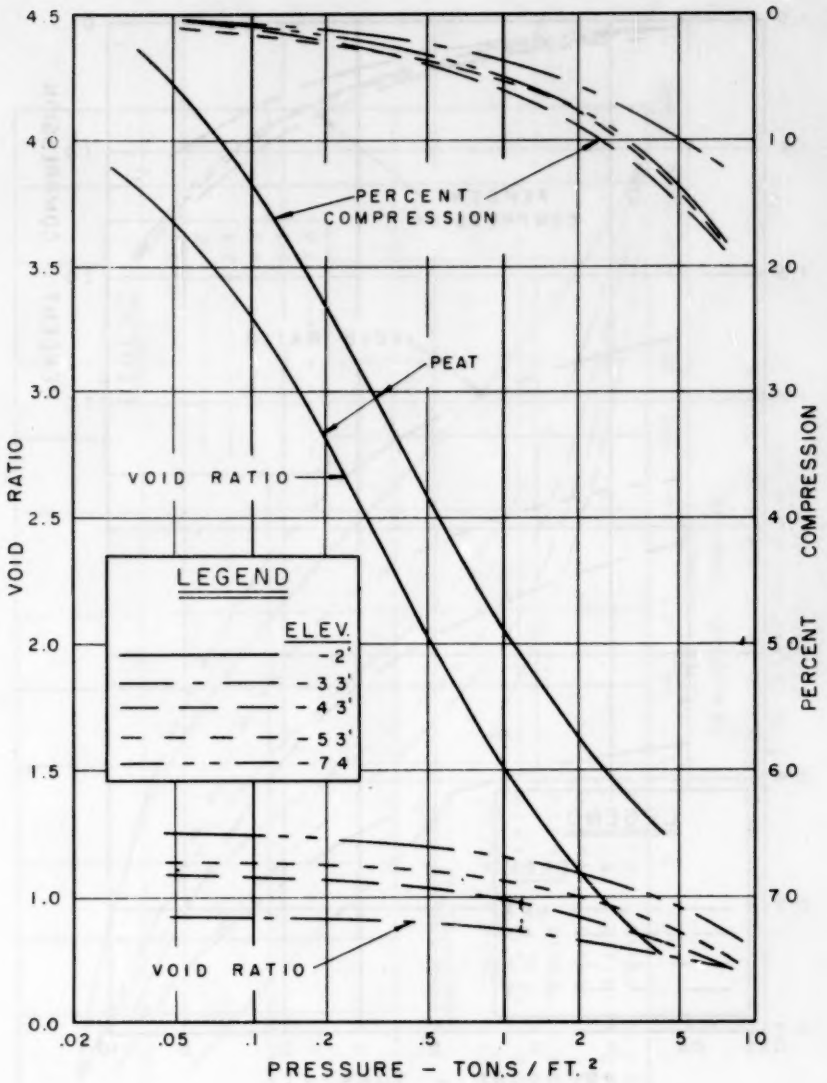
South Approach - Passaic River Bridge

Figure 2



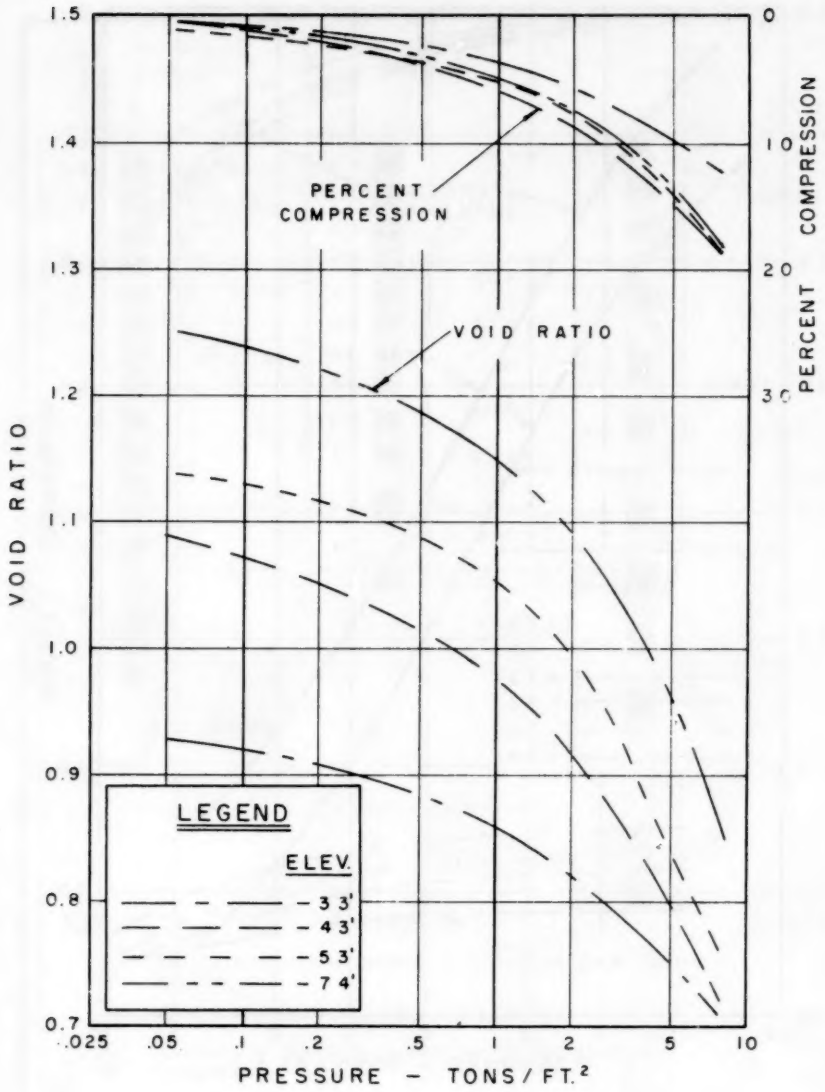
BORING LOGS — N.J. TURNPIKE

Figure 3



NEW JERSEY TURNPIKE
South Approach to Hackensack River Bridge
Typical Samples
of
clay and Peat
Boring No. 1

Figure 4

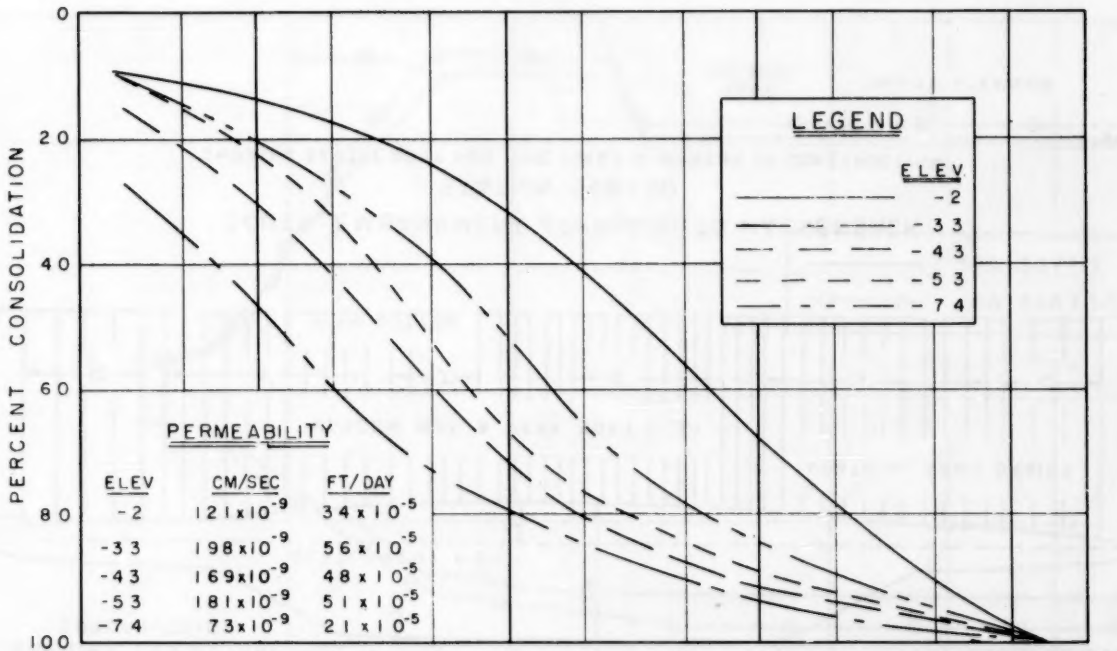


NEW JERSEY TURNPIKE
South Approach Hackensack River Bridge

Clay from Boring No. 1

Figure 5

571-24



NEW JERSEY TURNPIKE

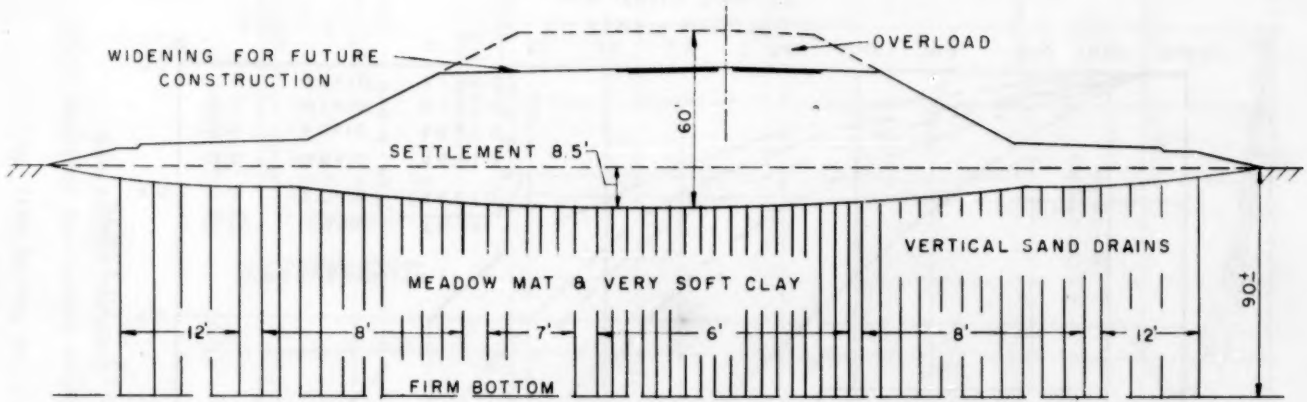
South Approach Hackensack River Bridge

Time Consolidation Curves

2 to 4 Ton Increment

Boring No. 1

Figure 6

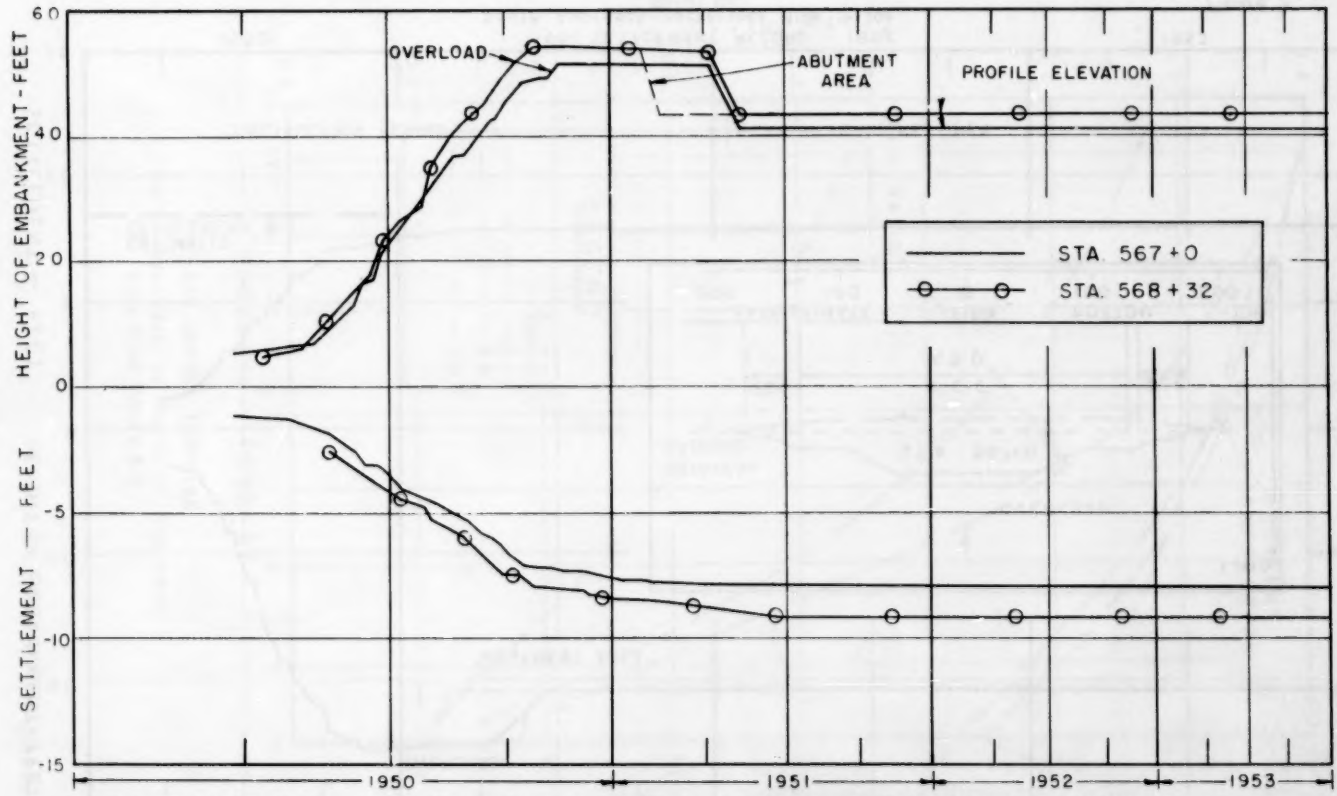


SOUTH EMBANKMENT APPROACH TO HACKENSACK

STATION 568+30

SHOWING SETTLEMENT FOR THE FIRST 6 MONTHS OF CONSTRUCTION

Figure 7



SETTLEMENT RECORD – Boring No 1 South Approach - Hackensack River Bridge (SEMI LOG PLOT) Figure 8

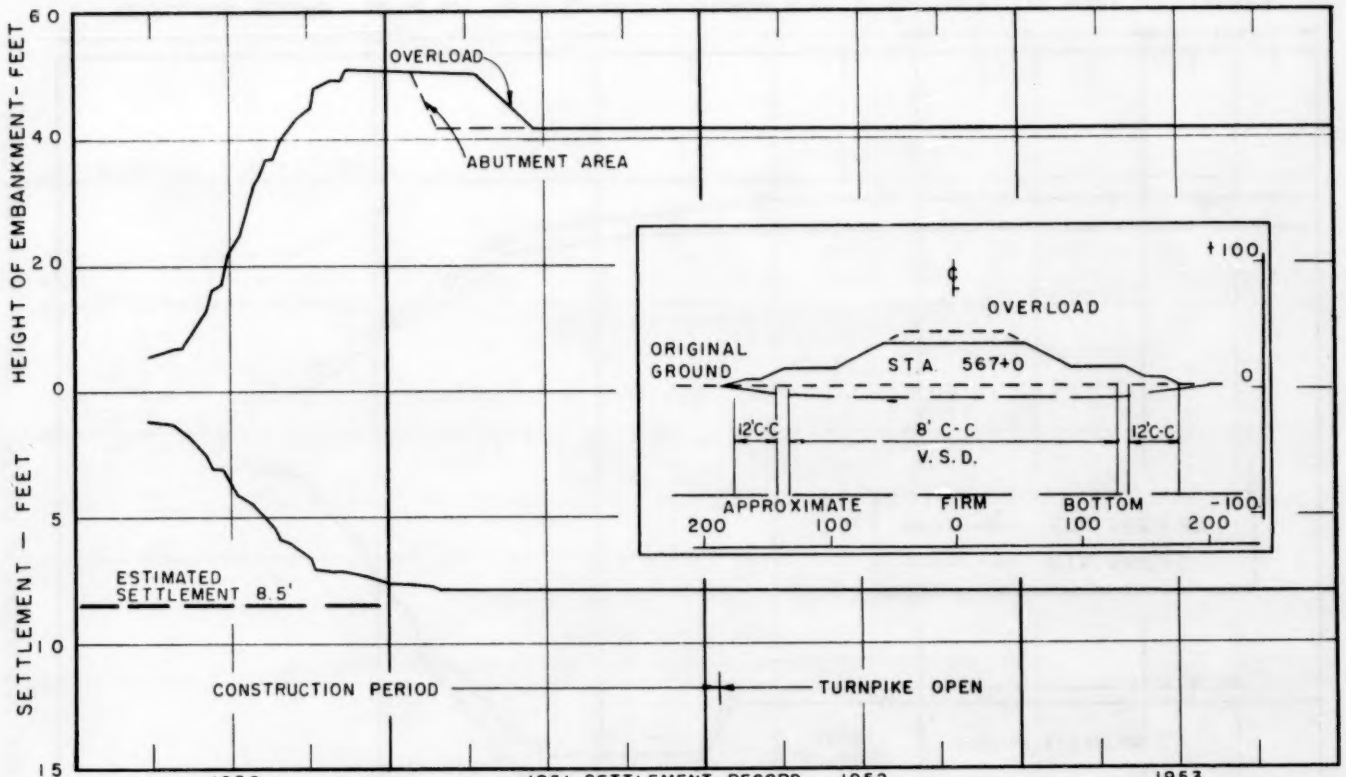
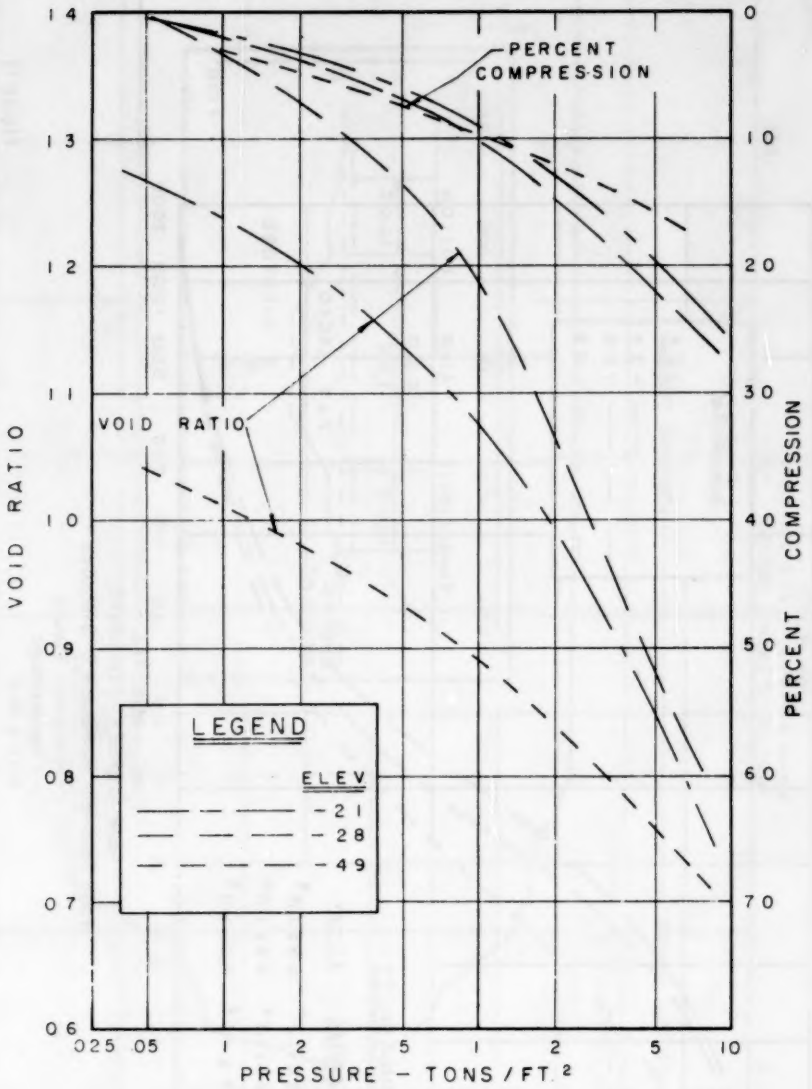

HEIGHT OF EMBANKMENT - FEET
SETTLEMENT — FEET
60
40
20
0
5
10
15
OVERLOAD
ABUTMENT AREA
ESTIMATED SETTLEMENT 8.5'
CONSTRUCTION PERIOD
TURNPIKE OPEN
1950
1951
1952
1953
SETTLEMENT RECORD
South Approach - Hackensack River Bridge
Boring No 1
+100
0
-100
OVERLOAD
ORIGINAL GROUND
STA 567+0
12'C-C
8' C-C
V. S. D.
12'C-C
APPROXIMATE
FIRM
BOTTOM
200
100
0
100
200

Figure 9

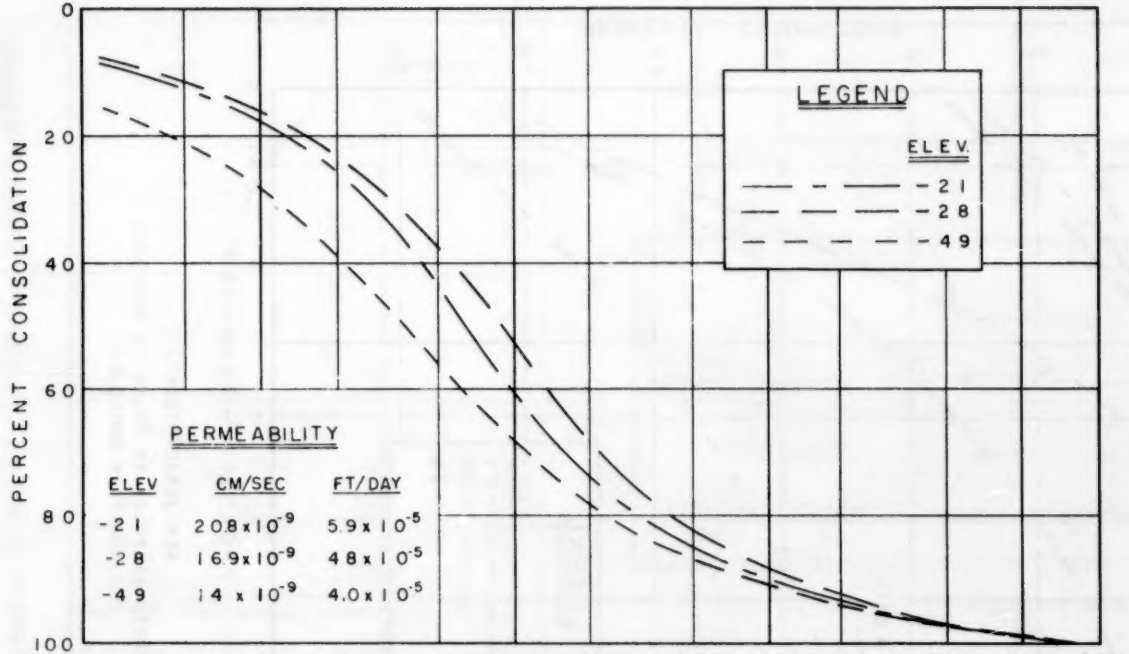


NEW JERSEY TURNPIKE

North Approach to Route #3 Overpass

Clay From Boring #2

Figure 10



NEW JERSEY TURNPIKE

North Approach to Route #3 Overpass

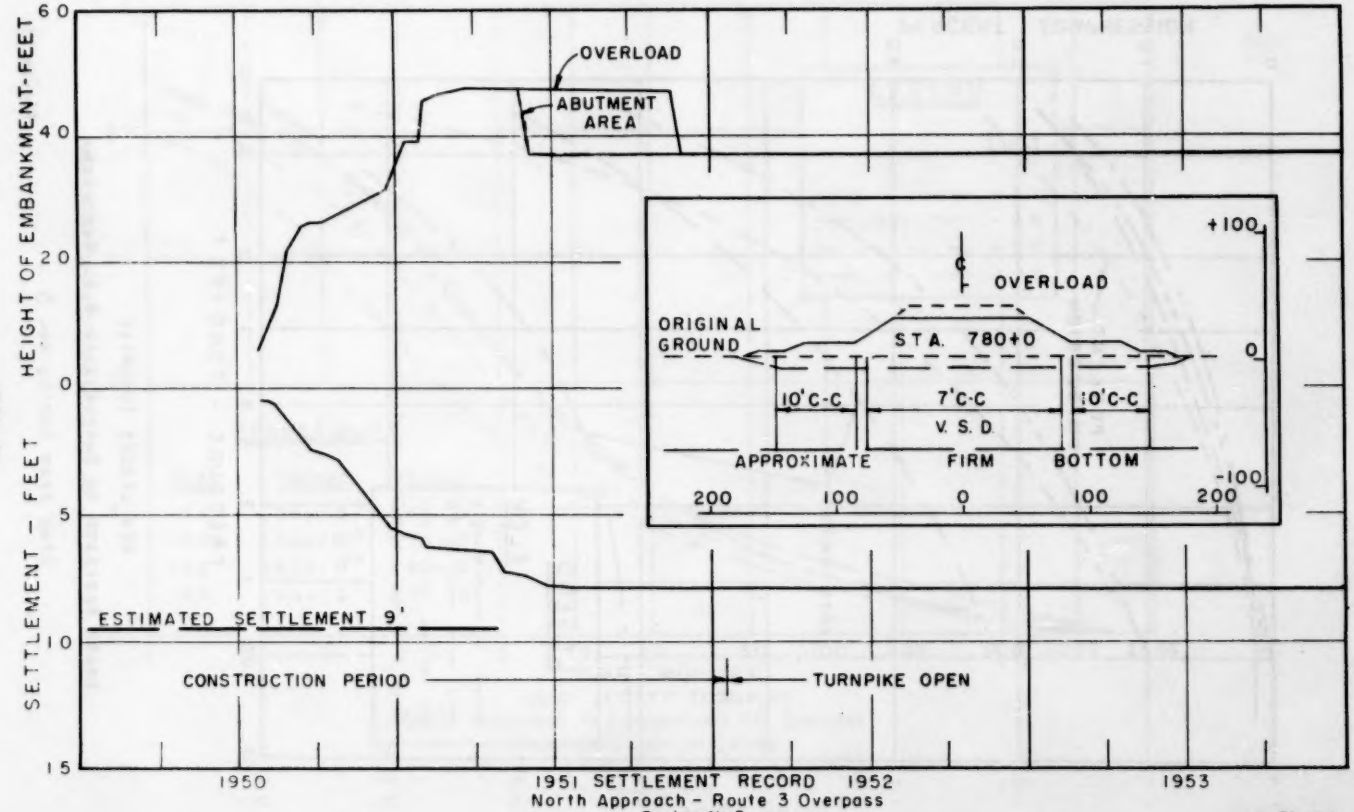
Time Consolidation Curves

2 to 4 Ton Increment

Boring No 2

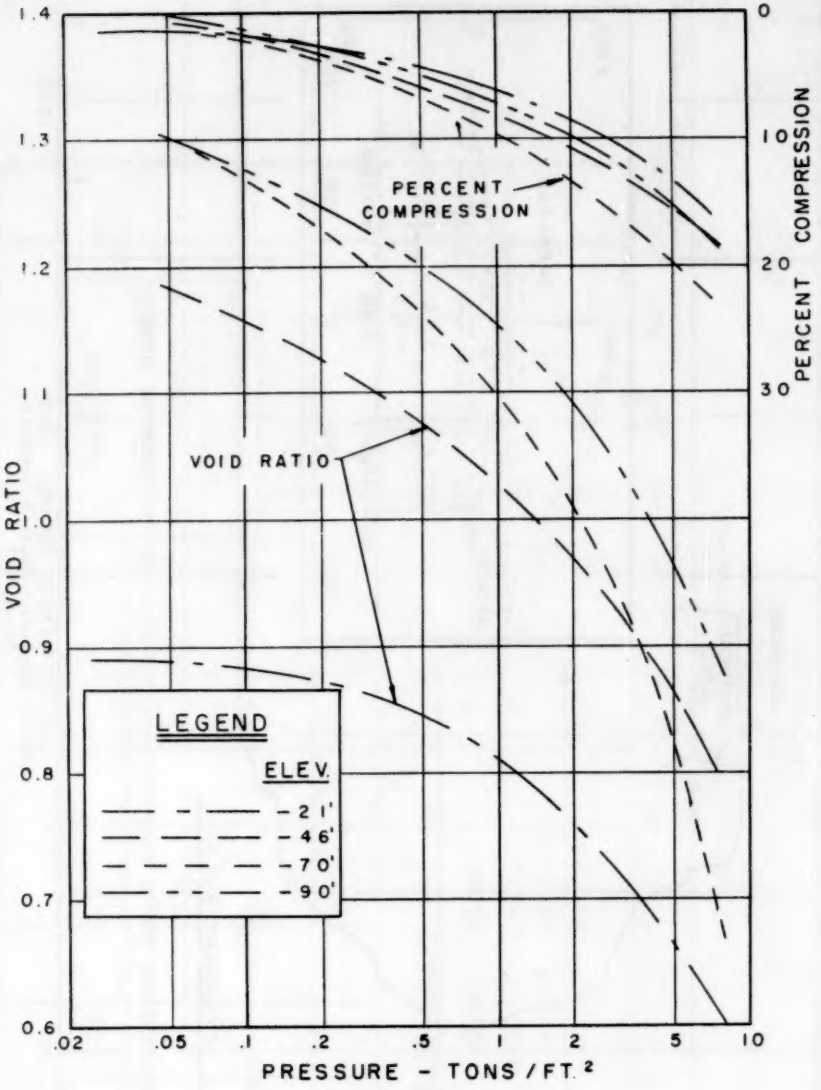
Figure 11

571-30



North Approach - Route 3 Overpass
Boring No 2

Figure 12

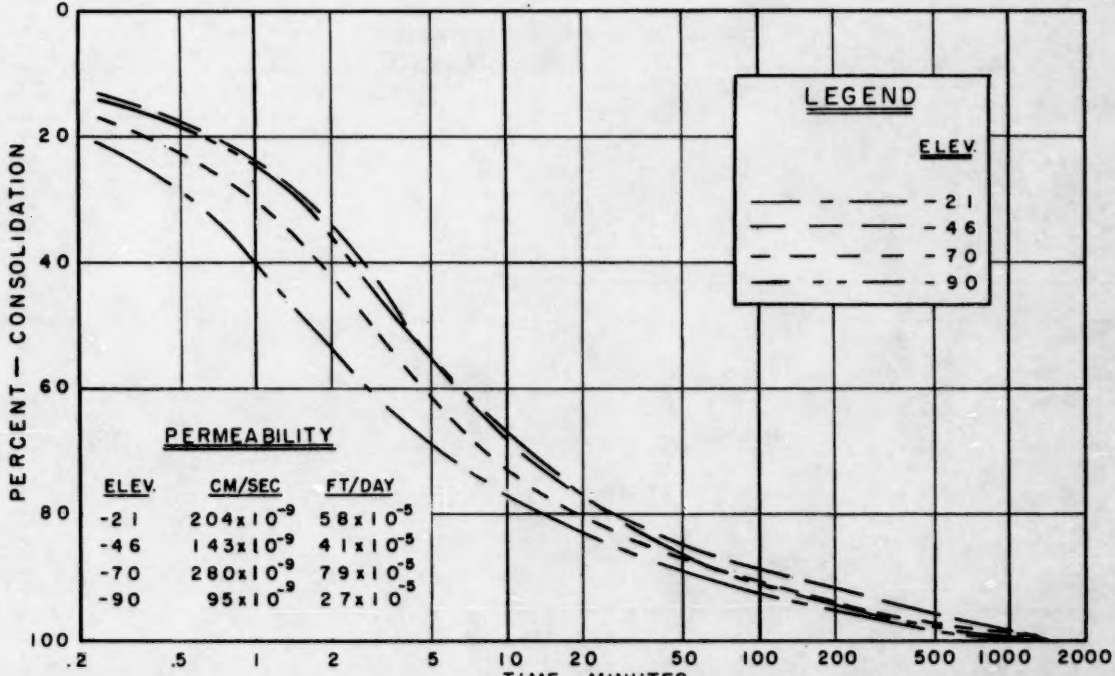


NEW JERSEY TURNPIKE

South Approach to Susquehanna R.R. Overpass

Clay from Boring No. 3

Figure 13



NEW JERSEY TURNPIKE
South Approach to Susquehanna R.R. Overpass
Time Consolidation Curves
2 to 4 Ton Increment
Boring No 3

Figure 14

571-33

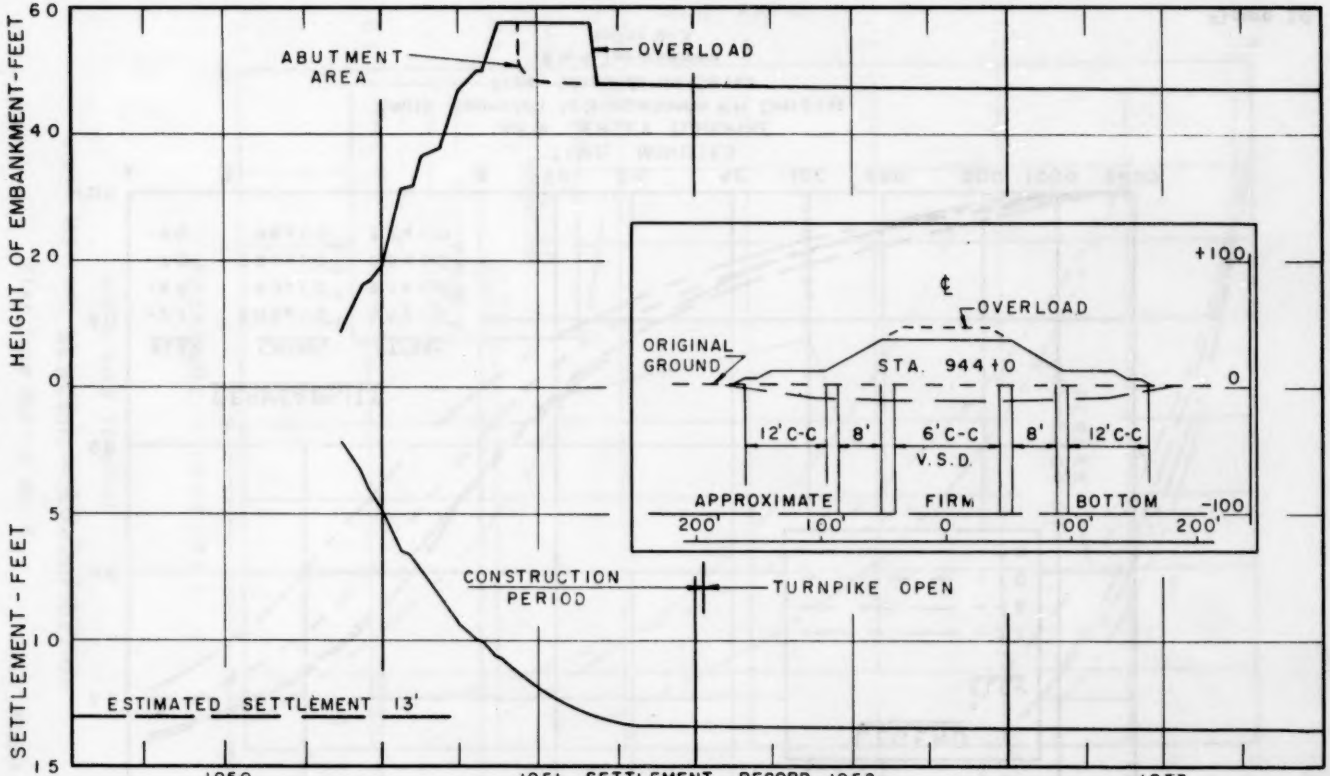

HEIGHT OF EMBANKMENT-FEET
SETTLEMENT - FEET
60
40
20
0
5
10
15
ABUTMENT AREA
OVERLOAD
ORIGINAL GROUND
STA. 944+0
+100
0
-100
℄
OVERLOAD
12' C-C
8'
6' C-C
V.S.D.
8'
12' C-C
APPROXIMATE
FIRM
BOTTOM
200'
100'
0
100'
200'
CONSTRUCTION PERIOD
TURNPIKE OPEN
ESTIMATED SETTLEMENT 13'
1950
1951
1952
1953
SETTLEMENT RECORD
South Approach Susquehanna R.R. Overpass
Boring No. 3

Figure 15